

OPTIMUM PLANT POPULATION FOR MAIZE-BEAN INTERCROPPING SYSTEM IN THE BRAZILIAN SEMI-ARID REGION

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ABSTRACT: Establishment of the ideal number of plant is a crucial point for obtaining maximum profits while cropping different species together. The main objective of the study was to investigate the effect of different plant populations of maize and beans, at two nitrogen levels, on the performance of the component crops. Two maize (20,000 and 40,000 plants ha⁻¹) and three bean (30,000; 60,000 and 90,000 plants ha⁻¹) populations were tested in a randomized complete block design with tree replicates. Grain yields of maize and beans were affected by intercropping and the effect was more detrimental to the legume mainly at the highest maize plant population. The application of nitrogen fertilizer to maize rows mitigated intercropping effect on maize at higher population (40,000 plants ha⁻¹) and, at lower maize plant population (20,000 plants ha⁻¹), benefited the associated beans by increasing grain yields. Land Equivalent Ratio values for grain yields of maize and beans showed that intercropping compared to sole cropping is advantageous and best indices were obtained at a bean plant population of 60,000 plants ha⁻¹.

Key words: *Zea mays*, *Phaseolus vulgaris*, cropping system, plant density

POPULAÇÃO ÓTIMA DE PLANTAS NO CONSÓRCIO MILHO-FEIJÃO NO SEMI-ÁRIDO BRASILEIRO

RESUMO: A definição do número de plantas por área é fundamental para a obtenção de ganhos quando diferentes espécies são plantadas juntas. O principal objetivo do estudo foi investigar o efeito de diferentes populações de plantas, sob dois níveis de nitrogênio, no desempenho do milho e do feijão em plantio consorciado. Duas populações de milho (20.000 e 40.000 plantas ha⁻¹) e três de feijão (30.000; 60.000 e 90.000 plantas ha⁻¹) foram testadas em um delineamento de blocos ao acaso com três repetições. As produções de grãos de milho e feijão foram afetadas pelo consórcio, sendo o efeito mais prejudicial para a leguminosa. A aplicação de fertilizante nitrogenado diminuiu o efeito competitivo do consórcio para o milho na maior população (40.000 plantas ha⁻¹), e, na menor população (20.000 plantas ha⁻¹), favoreceu o feijão com o aumento de sua produção de grãos. Os índices para Uso Eficiente da Terra para produção de grãos de milho e feijão revelaram que o consórcio é mais vantajoso que o plantio isolado das culturas, com os melhores valores com a população de plantas de feijão correspondente a 60.000 plantas ha⁻¹.

Palavras-chave: *Zea mays*, *Phaseolus vulgaris*, sistema de plantio, densidade de plantas

INTRODUCTION

The optimum plant population for maize in sole cropping is 40,000 plants ha⁻¹ under rainfed conditions in the semi-arid Northeast Brazil. Half of this population may be used in intercropping studies in row arrangements of one row of maize to two or three rows of beans (Rao & Morgado, 1984). Lima & Lopes (1981), in a plant population and spatial arrangement study on maize-bean intercropping, reported that intercropping was more advantageous than sole cropping and the highest Land Equivalent Ratios - LERs

were obtained in the spatial arrangement of one row of maize to two or three rows of beans.

In an intercropping study under temperate climate condition, when maize at a constant plant population was intercropped with three bean plant populations, Morgado & Willey (2003) showed that competitive effect of intercrop beans on maize yields was high at higher plant populations.

Morpho-physiological differences and agronomic factors such as the proportion of crops in the mixture and fertilizer application regulate competition between component crops for growth-limiting factors

plants each of maize and beans were cut at soil level and dried at 70°C for dry matter determination.

At harvest time one meter at each end of all plots was discarded as border. Outsider rows of sole and intercropped maize plots were discarded and three 6 m long middle rows were harvested. Harvest rows of intercropped beans were 6.4 m long and plants of all rows were harvested. Three 5.4 m long middle rows were harvested in sole cropped bean plots. Beans were harvested 78 DAS as dry seeds, and number and weight of pod per plant, seed weight per plot and individual pod weight were determined. Maize was harvested 115 DAS and plants were cut at soil level; weight and number of cobs and weight of grain per plot were determined. Three plants with cobs of all plots were dried at 70°C for dry matter determination.

Data Analysis

The experimental design was a randomized complete block with three replicates. The treatments consisted of a factorial combination of two maize plant populations; three bean plant populations and two levels of nitrogen fertilizer, corresponding to 12 intercropping treatments. There were three additional treatments: two nitrogen levels applied to sole maize and one sole bean treatment.

The Land Equivalent Ratio - LER is considered to be one of the most appropriate indices to evaluate the efficiency of intercropping system in producing better yields as compared with yields in sole cropping (Willey, 1985). The index was used to assess maize-bean intercropping advantages relative to sole cropping. Calculation of individual LER for maize considered yields of sole and intercropping systems at the same N level. The plant population of intercropped maize at M2 was similar to the plant population of sole cropped maize. For bean, calculation included a single sole cropping without nitrogen fertilizer.

The analysis of variance for maize at the final harvest combined the twelve factorial intercropping

treatments and the two nitrogen levels applied to sole maize. A probability of 5% or less ($p < 0.05$) of significance was considered to differentiate effects among treatments according to the Last Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Total dry matter accumulation per plant of maize in intercropping was not different from sole cropping in early stages of growth (Ofori & Stern, 1986). Variation on patterns of dry matter accumulation of intercropped maize due to bean population was marginal, with no consistent tendency after 33 DAS. Dry matter accumulation in all intercropped maize treatments increased with application of N2 (Table 1). Patterns for dry matter accumulation of intercropped maize show that effects of increasing maize plant population from M1 to M2 were very small given that number of plants at M2 was double of that at M1.

Competitive effect of maize at M1 and M2 on total dry matter accumulation of intercropped beans was similar in all three-bean populations at both nitrogen fertilizer levels until 43 DAS (Table 2). After this time, individual bean plant growth improved at M1 and was always higher than at M2 in all situations, mainly at 53 and 63 DAS. The highest maize plant population brought about greater competition for natural resources, i.e. light, water and nutrients, therefore dry matter accumulation of individual bean plant was lower than at M1. Tsubo et al. (2003) confirm these findings and show that the ratio of decreases in dry matter accumulation of intercropping increases throughout the season as compared to sole cropping.

Total biomass yield of intercropped maize per unit area tended to increase with increasing maize population from M1 to M2 (Table 3). Application of nitrogen increased dry matter yield per plant of intercropped maize at M2 in B1 and B2, and only in B3 at M1, as compared with N1 (Table 4). It seems

Table 1 - Dry matter of maize at two plant populations (M1, M2) intercropped with beans at three plant populations (B1, B2, B3) under two nitrogen levels (N1, N2).

DAS ⁽¹⁾	M1 N1			M2 N1			M1 N2			M2 N2		
	B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3
	----- g per plant -----											
23	6.40	4.50	6.40	5.21	4.11	6.79	5.86	7.10	7.08	6.03	6.55	6.20
33	30.15	28.95	30.12	18.02	15.15	20.65	24.69	21.99	32.10	23.94	18.67	27.94
43	78.29	65.36	45.72	35.60	34.38	62.10	59.29	61.38	75.58	59.27	61.40	60.38
53 ⁽²⁾	149.99	121.80	117.69	76.69	94.83	104.64	121.06	126.29	147.95	123.30	138.53	122.74
63	132.22	157.00	133.87	121.87	148.67	154.33	197.67	159.11	150.67	152.56	163.00	110.67

⁽¹⁾Days after sowing. ⁽²⁾Differences between numbers for maize population less than 18.8 and for bean population less than 23.0 are not different according to LSD test ($p < 0.05$).

Table 2 - Dry matter of beans under three plant populations (B1, B2, B3) intercropped with maize at two plant populations (M1, M2) under two nitrogen levels (N1, N2).

DAS ⁽¹⁾	B1 N1		B1 N2		B2 N1		B2 N2		B3 N1		B3 N2	
	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2
----- g per plant -----												
23	2.11	2.34	2.02	2.10	1.99	1.69	1.74	1.85	1.79	1.82	1.52	1.96
33	2.47	2.49	3.35	2.17	4.08	2.13	2.43	4.34	2.38	2.81	2.92	2.65
43	5.50	5.83	5.98	5.79	3.97	4.49	4.82	4.93	2.98	6.84	4.41	3.93
53(2)	10.74	4.05	9.21	6.76	11.80	5.86	11.06	6.15	7.09	5.78	9.70	7.67
63(3)	10.02	5.88	15.69	8.34	14.03	8.71	11.30	9.43	10.17	6.67	9.41	5.32

⁽¹⁾Days after sowing. Differences between numbers for maize population, at the same bean population and N level, less than ⁽²⁾2.3 and ⁽³⁾2.6 are not different according to LSD test ($p < 0.05$).

Table 3 - Biomass, grain yield and harvest index of maize under different cropping systems and nitrogen levels⁽¹⁾.

Cropping System ⁽²⁾	Biomass yield ⁽³⁾				Grain yield ⁽⁴⁾				Harvest index ⁽⁵⁾			
	N1		N2		N1		N2		N1		N2	
	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2
----- kg ha ⁻¹ -----												
----- % -----												
Intercropping												
B1	7527	10148	7187	12717	3175	4603	2951	5512	42.3	45.0	40.7	43.3
B2	8618	9469	8446	13958	3781	4593	3557	6195	43.3	48.7	42.0	45.0
B3	7516	11921	8508	12030	3181	5628	3408	5448	42.7	47.0	39.7	45.3
Mean	7887	10513	8047	12902	3379	4941	3305	5718	42.8	46.9	40.8	44.4
Sole cropping	10248		13122		4937		6157		48.0		46.7	

⁽¹⁾N1, N2 are 0 and 30 kg N ha⁻¹, and M1, M2 are plant populations 1 and 2 for intercropped maize, respectively. ⁽²⁾B1, B2, B3 are plant populations 1, 2 and 3 of intercropped beans, respectively. Differences between numbers for ⁽³⁾cropping system, maize population and N level less than 2345, 957 and 957, respectively. ⁽⁴⁾cropping system, cropping system × N level interaction less than 1028 and 839, respectively, and ⁽⁵⁾ cropping system, maize population and N level less than 5.3, 2.1 and 2.1, respectively, are not different according to LSD test ($p < 0.05$).

Table 4 - Yield attributes of maize grown under different cropping systems and nitrogen levels⁽¹⁾.

Cropping System ⁽²⁾	Dry matter per plant ⁽³⁾				Grain weight per plant ⁽⁴⁾				Cob per plant ⁽⁵⁾				Weight per cob ⁽⁶⁾			
	N1		N2		N1		N2		N1		N2		N1		N2	
	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2
----- g -----																
----- g -----																
Intercropping																
B1	341.5	241.9	340.4	307.5	144.2	109.7	139.7	133.2	1.14	0.98	1.11	0.99	155.7	139.9	160.0	168.4
B2	404.8	234.9	418.1	337.5	157.1	114.0	176.3	149.7	1.28	1.03	1.38	1.07	169.0	136.5	161.7	176.7
B3	338.5	290.4	396.9	290.8	143.3	137.2	158.1	131.7	1.07	1.11	1.24	0.98	169.2	152.0	162.2	168.5
Sole cropping	252.9		321.2		121.9		150.4		1.03		1.08		150.0		177.4	

⁽¹⁾N1, N2 are 0 and 30 kg N ha⁻¹, and M1, M2 are plant populations 1 and 2 for intercropped maize, respectively. ⁽²⁾B1, B2, B3 are plant populations 1, 2 and 3 of intercropped beans, respectively. Differences between numbers for ⁽³⁾cropping system, maize population and N level less than 66.4, 14.7 and 14.7, respectively, ⁽⁴⁾cropping system, maize population and bean population less than 27.4, 11.2 and 13.7, respectively, ⁽⁵⁾cropping system, maize population and bean population less than 0.17, 0.07 and 0.09, respectively, and ⁽⁶⁾N level less than 11.4 are not different according to LSD test ($p < 0.05$).

that bean plants at B1 and B2 were not competing for available soil nitrogen in a high degree at M1, as compared with B3.

Raising bean population from B1 to B2 increased total biomass yield of intercropped maize at

M1 by 14% and 17% at N1 and N2, respectively. On the other hand, the increase for B3, compared to B1 at N2, corresponded to 18%. Total biomass yield in M2 at N1 was 17% higher in B3 than with B1, being similar to N2 situation (Table 3). This implies that

maize plants might have had more nitrogen available to absorb when intercropped with beans at higher populations.

Total biomass yield of sole maize at M2 and with fertilizer was higher than under intercropping at M1 in all situations (Table 3). Maize at M2, with the application of nitrogen and intercropped with beans at B2 showed total biomass yield significantly higher than and similar to sole cropping at N1 and N2, respectively. Nitrogen fertilizer improved total biomass yield of sole maize (Table 3).

Dry matter yield per plant at M1 was higher in all intercropping situations as compared with M2 (Table 4). The higher maize population increased grain yield per unit area of intercropped maize (Table 3). The increase, averaged over bean population, was higher at N2 (73%) than at N1 (46%). Cardoso et al. (1993) reported an increase of 37% in grain yield for the same rate of plant population in a maize-cowpea intercropping under irrigation condition. Grain yield per plant was significantly higher in M1 than in M2 (Table 4). This suggests an intra-specific competition for natural resources among intercropped maize plants at a higher population. Grain yield per unit area of intercropped maize tend to increase as bean population was increased from B1 to B2 (Table 3). This is attributed to increases in grain yield and number of cobs per plant (Table 4).

The main yield components for the increase in grain yield per unit area, due to application of nitrogen, were grain yield and number of cobs per plant (Table 4). Intercropping decreased grain yield of maize at M1, compared with sole cropping. The rates of reduction for mean over bean population were 32% and 46% at N1 and N2, respectively (Table 3). Similarly, Silwana & Lucas (2002) showed a decreasing intercropping effect on maize yield of 34% when maize at

20,000 plants ha⁻¹ was intercropped with beans at 100,000 plants ha⁻¹, as compared to sole maize at 40,000 plants ha⁻¹. At M2, grain yield of intercropped maize was not much different from sole cropping at similar nitrogen levels, but the highest yield, obtained at B2-N2, was higher than the yield for sole cropped maize at N1. This is in agreement with early findings by Francis et al. (1978) for a maize-bean intercropping, where maize grain yields did not differ between sole and intercropping systems at a constant maize population.

Grain yield per unit area of intercropped beans decreased as maize population increased from M1 to M2 (Mutungamiri et al., 2001) in all bean populations at N2 and in B2 at N1 (Table 5). Decreases were caused by reduction on number of pods per plant. Increases in bean population increased grain yield per unit area of intercropped beans, mainly at N2 in B2 and B3 at both maize populations, as compared with B1. Nitrogen applied to maize rows tended to increase intercropped beans grain yield per unit area at M1, especially in B2 and B3. Number of pods per plant was the yield component most responsible for the increase (Table 5). It seems that beans probably benefited from the N applied to maize rows as the plants got closer to maize rows in B2 (1:2) and B3 (1:3) (Siame et al., 1997; Morgado & Willey, 2003).

Harvest index of intercropped maize increased in all three-bean populations at both nitrogen levels as the maize population increased from M1 to M2 (Table 3), showing that the rate of increases due to increasing maize population was higher in grain yield than in total biomass yield. This effect was different in temperate climate under rainfed conditions, where maize harvest indices decreased with increase in maize population above optimum (Morgado & Willey 2003). Harvest index of intercropped maize tended to decrease

Table 5 - Seed yield and yield attributes of beans grown under different cropping systems and nitrogen levels⁽¹⁾.

Cropping System ⁽²⁾	Grain yield ⁽³⁾				Grain weight per plant ⁽⁴⁾				Pod number per plant ⁽⁵⁾				Weight per cob ⁽⁶⁾			
	N1		N2		N1		N2		N1		N2		N1		N2	
	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2
	----- kg ha ⁻¹ -----				----- g -----								----- g -----			
Intercropping																
B1	104	64	104	50	5.19	2.84	5.90	2.09	5.5	3.3	6.3	2.4	1.44	1.19	1.33	1.41
B2	169	89	261	128	4.33	4.27	7.14	3.73	5.8	5.3	7.9	4.9	1.10	1.23	1.25	1.11
B3	131	123	272	130	2.77	2.42	5.37	3.19	3.9	3.0	5.7	4.3	1.07	1.13	1.34	1.09
Sole cropping	563				6.56				9.1				1.10			

⁽¹⁾N1, N2 are 0 and 30 kg N ha⁻¹, and M1, M2 are plant populations 1 and 2 for intercropped maize, respectively. ⁽²⁾B1, B2, B3 are plant populations 1, 2 and 3 of intercropped beans, respectively. Differences between numbers for ⁽³⁾maize population and bean population less than 54 and 66, ⁽⁴⁾maize population less than 1.46. ⁽⁵⁾maize population and bean population less than 0.96 and 1.18, respectively, and ⁽⁶⁾maize population and N level less than 0.84 and 0.84, respectively, are not different according to LSD test ($p < 0.05$).

Table 6 - Land Equivalent Ratio for grain yield of maize and bean intercrops and total grain yield.

Bean population	Maize population 1						Maize population 2					
	0 kg N ha ⁻¹			30 kg N ha ⁻¹			0 kg N ha ⁻¹			30 kg N ha ⁻¹		
	Maize ⁽¹⁾	Beans ⁽²⁾	Total ⁽³⁾	Maize ⁽¹⁾	Beans ⁽²⁾	Total ⁽³⁾	Maize ⁽¹⁾	Beans ⁽²⁾	Total ⁽³⁾	Maize ⁽¹⁾	Beans ⁽²⁾	Total ⁽³⁾
B1	0.66	0.26	0.90	0.48	0.37	0.85	0.96	0.11	1.07	0.90	0.13	1.03
B2	0.76	0.56	1.28	0.58	0.60	1.18	0.94	0.28	1.22	1.01	0.63	1.64
B3	0.66	0.27	0.93	0.55	0.59	1.14	1.16	0.28	1.34	0.89	0.33	1.22

Differences between numbers for ⁽¹⁾maize population, at same N level, and for N level, at same maize population, less than 0.12, ⁽²⁾bean population, at same maize population and N level, less than 0.21 and ⁽³⁾bean population, at same maize population and N level, less than 0.28 are not different according to LSD test ($p < 0.05$).

with nitrogen application in all bean populations at M2, and in B3 at M1 (Table 3). Intercropping tended to decrease harvest index of maize, being lower at M1 in all the situations, except for B2 – N1, as compared with sole cropping at N1.

Harvest index of maize was higher in sole than in intercropping (Oljaca et al., 2000) but declined as nitrogen fertilizer was applied (Table 3). Maize LERs were higher at M2 than at M1 in all three-bean populations at both nitrogen fertilizer situations, because of a greater competition by higher maize population (Table 6). Application of nitrogen tended to decrease maize LERs in both maize populations (Ofori & Stern, 1987). This effect was significant at M1 in all bean populations and at M2 in B3. The lower maize LERs under nitrogen fertilizer condition were brought about by higher increases in grain yield of sole cropping as compared with the increases in intercropping. Maize LERs tended to increase with increasing bean populations, and in B3 maize LER for M2 at N1 was 16% (LER = 1.16) higher than in sole cropping (LER = 1.00). Maize plants possibly made a better use of soil resources, i.e. water and nutrients, when intercropped with beans at B2 and B3.

Bean LERs increased with increases in bean population at M1 in all situations, except in B3 at N1, and at M2 only in B2 with nitrogen application. Nitrogen fertilizer tended to increase bean LERs. Increases were more evident at B2 and B3 where the bean plants were closer to maize rows. This might be attributed to the fact that bean plants possibly benefited from the nitrogen applied to maize rows (Siame et al., 1997; Morgado & Willey, 2003). Increasing maize population from M1 to M2 decreased bean LERs. This effect was greatest at B1.

Total LERs tended to increase with increasing bean populations due to higher bean LERs and to increases in maize LERs, mainly at M1 in all situations, except in B3 at N1 level and at M2 in B2 with application of N2. Nitrogen fertilizer increased total LERs in B2 at M2 and B3 at M1. The highest total LERs at M1, 1.28 and 1.18, were

obtained with B2 at N1 and N2, respectively. Both maize and bean components were higher at B2 than at B1 and B3, suggesting that maize and beans at that situation had an optimum balanced plant population and could make a better use of natural resources. At M2, the highest total LER (1.64) with nitrogen fertilizer application was also obtained in B2. For the no nitrogen-applied situation, the highest total LER (1.34) was obtained in the highest bean population (B3) where maize component had the highest LER (1.16).

As a conclusion, intercropping is more productive than sole cropping and advantage as high as 28% and 64%, were obtained at M1 and M2 respectively.

REFERENCES

- CARDOSO, M.J.; FREIRE FILHO, F.R.; RIBEIRO, V.Q.; FROTA, A.B.; MELO, F.B. Densidade de plantas no consórcio milho x caupi sob irrigação. *Pesquisa Agropecuária Brasileira*, v.28, p.93-99, 1993.
- CARDOSO, M.J.; FREIRE FILHO, F.R.; RIBEIRO, V.Q.; FROTA, A.B.; MELO, F.B. Arranjo populacional no consórcio milho x feijão macassar (*Vigna unguiculata* (L.) Walp.) em regime de sequeiro. *Revista Ceres*, v.41, p.19-27, 1994.
- CHOWDHURY, M.K.; ROSARIO, E.L. Comparison of nitrogen, phosphorus and potassium utilization efficiency in maize/mungbean intercropping. *Journal of Agricultural Science*, v.122, p.193-199, 1994.
- FARIS, M.A.; BURITY, H.A.; REIS, O.V.; MAFRA, R.C. Intercropping sorghum or maize with cowpea or common beans under two fertility regimes in the Northeast Brazil. *Experimental Agriculture*, v.19, p.251-261, 1983.
- FRANCIS, C.A.; FLOR, C.A.; PRAGUE, M. Effects of bean association on yields and yield components of maize. *Crop Science*, v.18, p.760-764, 1978.
- LIMA, A.F.; LOPES, L.H.O. Plant population and spatial arrangement study on the intercropping of maize and beans (*Phaseolus vulgaris* L.) in Northeast Brazil. In: INTERNATIONAL WORKSHOP ON INTERCROPPING, Patancheru, 1979. Proceedings. Patancheru: ICRISAT, 1981. p.41-45.
- MAFRA, R.C.; LIRA, M.A.; ARCOVERDE, A.S.S.; LIMA, G.R.; FARIS, M.A.O. O consórcio de sorgo e milho com os feijões de arranca e macassar no Nordeste do Brasil. *Pesquisa Agropecuária Pernambucana*, v.3, p.93-104, 1979.
- MORGADO, L.B. Estudo sobre densidade de plantio de sorgo e feijão-caupi consorciados no semi-árido brasileiro. *Revista Ciência Agrônômica*, v.37, p.357-363, 2006.

- MORGADO, L.B.; WILLEY, R.W. Effect of plant population and nitrogen fertilizer on yield and efficiency of maize-bean intercropping. **Pesquisa Agropecuária Brasileira**, v.38, p.1257-1264, 2003.
- MUTUNGAMIRI, A.; MARIGA, I.K.; CHIVINGE, A.O. Evaluation of maize (*Zea mays* L.) cultivars and density for dryland maize-bean intercropping. **Tropical Agriculture**, v.78, p.8-12, 2001.
- OFORI, F.; STERN, W.R. Maize/cowpea intercrop system: effect of nitrogen fertilizer on productivity and efficiency. **Field Crops Research**, v.14, p.247-261, 1986.
- OFORI, F.; STERN, W.R. The combined effect of nitrogen fertilizer and density of legume component on production efficiency in a maize/cowpea intercropping system. **Field Crops Research**, v.16, p.43-52, 1987.
- OLJACA, S.; CVETKOVIC, R.; KOVACEVIC, D.; VASIC, G.; MOMIROVIC, N. Effect of plant arrangement pattern and irrigation on efficiency of maize (*Zea mays*) and bean (*Phaseolus vulgaris*) intercropping system. **Journal of Agricultural Science**, v.135, p.261-270, 2000.
- RAO, M.R.; MORGADO, L.B. A review of maize-beans and maize-cowpea intercropping systems in the semi-arid Northeast Brazil. **Pesquisa Agropecuária Brasileira**, v.19, p.179-192, 1984.
- RUSSELL, J.T.; CALDWELL, R.M. Effect of component densities and nitrogen fertilization on efficiency and yield of maize/soybean intercrop. **Experimental Agriculture**, v.25, p.529-540, 1989.
- SIAME, J.; WILLEY, R.W.; MORSE, S. A study of the partitioning of applied nitrogen between maize and beans in intercropping. **Experimental Agriculture**, v.33, p.35-41, 1997.
- SILWANA, T.T.; LUCAS, E. O. The effect of planting combinations and weeding on the growth and yield of component crops of maize/bean and maize/pumpkin intercrops. **Journal of Agricultural Science**, v.138, p.193-200, 2002.
- TRENBATH, B.R. Resource use by intercrops. In: FRANCIS, C.A. (Ed.) **Multiple cropping systems**. New York: Macmillan, 1986. chap.4, p.57-81.
- TSUBO, M.; MUKHALA, E.; OGINDO, H.O.; WALKER, S. Productivity of maize-bean intercropping in a semi-arid region of South Africa. **Water SA**, v.29, p.381-388, 2003.
- WILLEY, R.W. Intercropping: its importance and research needs. Part 1. Competition and yield advantages. **Field Crops Research**, v.32, p.1-10, 1979.
- WILLEY, R.W. Evaluation and presentation of intercropping advantages. **Experimental Agriculture**, v.21, p.119-133, 1985.

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